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Improving the resilience of the UK labour force in a 1.5°C world

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Abstract

Climate change is already having a measurable impact on labour forces across the globe, with far reaching implications for economic growth, in addition to worker health, firm profitability, poverty and inequality, and food security, to name but a few. This study quantifies the impacts of heat stress on the UK labour force, focusing on labour supply, labour productivity, the health of workers, and the extent to which and how adaptation and adaptive capacity is reducing the negative impacts of extreme heat. We collected data in 2024 during the UK summer, just after a period of anomalous heat, surveying over 2,000 people in the UK labour force, when their recollection of the heat episode was fresh in their memories. Using microeconometric analysis and controlling for a rich set of demographic, occupational, and adaptation covariates, our results clearly show that workers do perceive their health to be harmed by heat stress, and workers and employers rely on a wide range of adaptation measures to protect their health that are at least partially effective. Our results suggest that a 1°C positive temperature anomaly from the long-term average increased the probability of a worker reducing their hours by 9.9% and their effort by 9.5%. However, for workers who received advanced alerts of heat episodes, those probabilities are 6.2% and 6.7% respectively, suggesting that adaptation is only partially effective. In the case of worker health, advanced alerts reduced the probability of workers reporting adverse health effects due to heat episodes by approximately 5 percentage-points.

Keywords: heat stress, labour force, temperature, adaptation

1. Introduction

Climate change, as manifested in increasing heat and frequency and intensity of heatwaves, is already having a measurable impact on the labour force (Dasgupta and Robinson, 2023), in terms of both how workers' health is affected by heat anomalies, and how workers can best adapt to these changing work conditions (Dasgupta et al.,

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2024; Shayegh and Dasgupta, 2022; Parsons et al., 2022; Dasgupta et al., 2021; Schleypen et al., 2022; Antonelli et al., 2020). Yet to date there is very little if any rigorous detailed quantitative information on how labour supply and worker health are affected, the extent to which workers are already actively adapting to periods of heat, which workers are more or less able or empowered to adapt, and the extent to which interventions, such as early warning systems, are proving effective. Given that the consequences of heat on the workforce are likely to be far reaching and worsening over time without effective adaptation, potentially affecting worker health, firm profitability, economic growth, poverty, inequality, and food production, to name just a few, there is a clear need for rigorous analysis and quantification of these effects.

Recognising a gap in knowledge and understanding, this study provides one of the first rigorous and granular empirical analyses of how heat stress is affecting workers in the UK, in terms of working hours, labour productivity, and health of workers, with a focus on the extent to which adaptation can reduce the negative impacts. In this paper we combine labour force survey data that we collected in August 2024, just after a distinct heat anomaly in the UK when workers' recollection was fresh in their memories, with spatially-disaggregated daily temperature anomaly data from the UK Met Office over the long-term 1961-1990 average for July. Using microeconometric analysis, and controlling for a rich set of demographic, occupational, and adaptation covariates, our results clearly show that labour supply, labour productivity, and worker health are harmed by heat. Adaptations allow workers to partially reduce the negative impact of heat on working hours and productivity, and enable workers to protect their health. Workers whose employers have introduced adaptations appeared to be less likely to have perceived their health as being harmed during the heat episode, emphasising that employers that invest in adapting work environments to heat can reduce losses in labour supply and labour productivity due to heat stress, and protect their employees' health, which also reduces absenteeism.

This research builds a rich and nuanced understanding of how workers in the UK perceive and adapt to heat. It is also particularly timely. First, there is little rigorous understanding of whether and how workers adapt to extremes of heat; nor whether workers, employers, and governments, understand the impact of heat and heatwaves on livelihoods, health, productivity, and economic output. Second, the effect of interventions such as early warning systems and alerts on the workforce are also unknown. Third, unlike most European countries, the UK does not have a statutory maximum working temperature (European Environment Agency, 2022), though this is increasingly being discussed. Fourth, most economic models exclude adaptation, and policy makers have insufficient guidance on where to focus their adaptation efforts to maximise health and economic benefits.

The rest of the paper is as follows. In Section 2 we provide a concise review of the literature on adaptation in the labour force. In Section 3 we give contextualise the study, the UK's heat episode during summer 2024. Our methodological approach is detailed in Section 4, results are reported in Section 5, and we conclude in Section 6 with a discussion of the results, and implications for policy and future research.

2. Adaptation in the labour force

Climate change adaptation has been described as 'anticipating the adverse effects of climate change and taking appropriate action to prevent or minimise the damage these effects can cause, or taking advantage of opportunities that may arise' (Triple

E Consulting, 2014). In the context of the labour force, adaptation can be undertaken autonomously by workers to protect their health or income, also referred to as spontaneous adaptation, in which adjustments are made without deliberate planning, triggered, for example, by specific climate stimuli (McCarthy and IPCC, 2001); introduced unilaterally by employers; or stipulated by government.

There are many examples of autonomous adaptation to heat in the workplace by individual workers, including adjusting work hours, rehydration (Robinson et al., 2024); decreasing work intensity or taking more frequent breaks (Watkiss et al., 2021); and improving heat resilience by increasing physical fitness and having appropriate clothing (Havenith et al., 2002). Adjustments made by employers include installing air conditioning and modifying work schedules; allowing flexible working; moving staff away from windows (the source of heat); and temporarily relaxing workplace dress codes (Dasgupta et al., 2024). Shifting outdoor work to earlier morning or night hours, whether autonomous or suggested by employers, can reduce heat exposure and boost overall daily labour productivity, and has been proven to be effective (Takakura et al., 2018). However, it can be impractical for those with limited free time or long working days (Vivid Economics, 2017), and can have potential negative impacts on worker health and safety, including increased fatigue and accidents due to disrupted sleep patterns leading to impaired performance and increased safety risks (Smith, 2012; Wickwire et al., 2017; Robinson et al., 2024).

Despite considerable adaptation to heat already occurring in the workplace, the limited evidence to date suggests that there is likely already a gap between implemented adaptation and the additional adaptation required to meet social and humanitarian objectives (Dasgupta et al., 2024). Further, estimates suggest that 22–68% of the global economic losses due to decreased labour productivity from heat by 2100 could be avoided through adaptation measures, such as air conditioning installation and working hours shifting (Zhao et al., 2021). Well-designed early warning systems have the potential to significantly reduce the harmful effects of heat stress, particularly for vulnerable populations and workers (Robinson and Dasgupta, 2024).

England has a Heatwave Plan, while the devolved administrations engage severe weather alert systems during heatwaves (Surminski et al., 2021). In 2023, the Adverse Weather and Health Plan (AWHP) was launched to replace the former Heatwave Plan (HWP) for England. An assessment of the effectiveness of the AWHP found that while it had been well received and was effective in addressing immediate heat risks, there was room for improvement in public communication and cross-sectoral collaboration to fully understand and mitigate the broader impacts of heat (Ravishankar and Howarth, 2024)

The UK's Workplace (Health, Safety, and Welfare) Regulations from 1992 and the 1999 Management of Health and Safety at Work Regulations require employers to provide a reasonably comfortable workplace temperature to protect workers from excessive heat. This includes measures such as insulation, air conditioning, and workstation placement (Surminski et al., 2021). However, unlike many European countries, the UK does not have a statutory maximum working temperature (European Environment Agency, 2022). Health and safety regulations mandate a comfortable workplace, yet only excessive cold is specified, along with a recommended minimum temperature (Dasgupta et al., 2024; European Environment Agency, 2022). There have been suggestions that the government should consider introducing maximum workplace temperatures, particularly for physically demanding roles (European Environment Agency, 2022; Dasgupta and Robinson, 2023; Dasgupta et al., 2024).

Many UK organisations do already have policies linked to heat. For example, the British Red Cross has hot weather check lists, and operational notes to ensure staff and volunteers are aware of heatwaves, as well as the measures they can take to keep cool (British Red Cross, 2024). To warn of heatwaves, Public Health England uses a heat-health watch alert system based on Met Office data, primarily aimed at health professionals. However, some organisations have implemented interventions that could be seen as having the potential to drive maladaptation. For example, Oxfordshire County Council (OCC) supplies sun cream for people working in direct sunlight (Trade Union Congress, 2009), which arguably could encourage workers to spend longer working in the sun and as such increase heat stress.

3. Heat and heatwaves in the UK

The UK's five warmest years on record have occurred since 2006, and the ten warmest years since 2003 (Figure 1). Globally, 2024 was the warmest year on record (ECMWF, 2025). Heatwaves are likely to become more frequent and more severe until at least 2050, regardless of any successes in achieving global net zero targets (Robinson et al., 2024). 2022 was a landmark year for the UK climate as it was the UK's warmest year on record (annual mean temperature of 10°C), surpassing the previous record set in 2014, and characterized by two unprecedented heat events: a record-breaking daily maximum temperature exceeding 40°C; and an annual average temperature surpassing 10°C for the first time (Mccarthy et al., 2023). A Level 4 heat-health warning (UK Health Security Agency, 2004) was issued by the Department for Health and Social Care and the UK Health Security Agency (UKHSA) for the first time on 18 and 19 July (Howarth et al., 2023). The likelihood of both these extreme occurrences is increased by human-induced climate change (Carbon Brief, 2022).

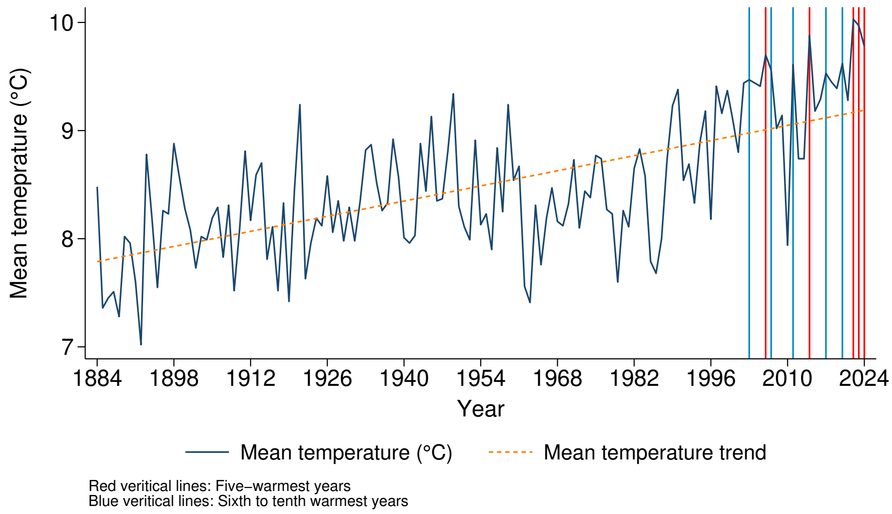

Figure 1: Annual mean temperature for the UK (1884 - 2024). The dashed orange line shows the trend in mean temperature. The red vertical lines represent the five warmest years since 1884.

In summer 2024, though the UK did not experience a heatwave, there was a period of extreme heat, with a mean temperature of 14.8°C during July 2024, 0.4°C higher than the long-term average July mean temperature, 1961-1990; and temperatures reaching above 30°C towards the end of July. The highest temperature of

32°C was recorded at Kew Gardens, London, and Heathrow, London, on 30 July 2024 (Figure 2).

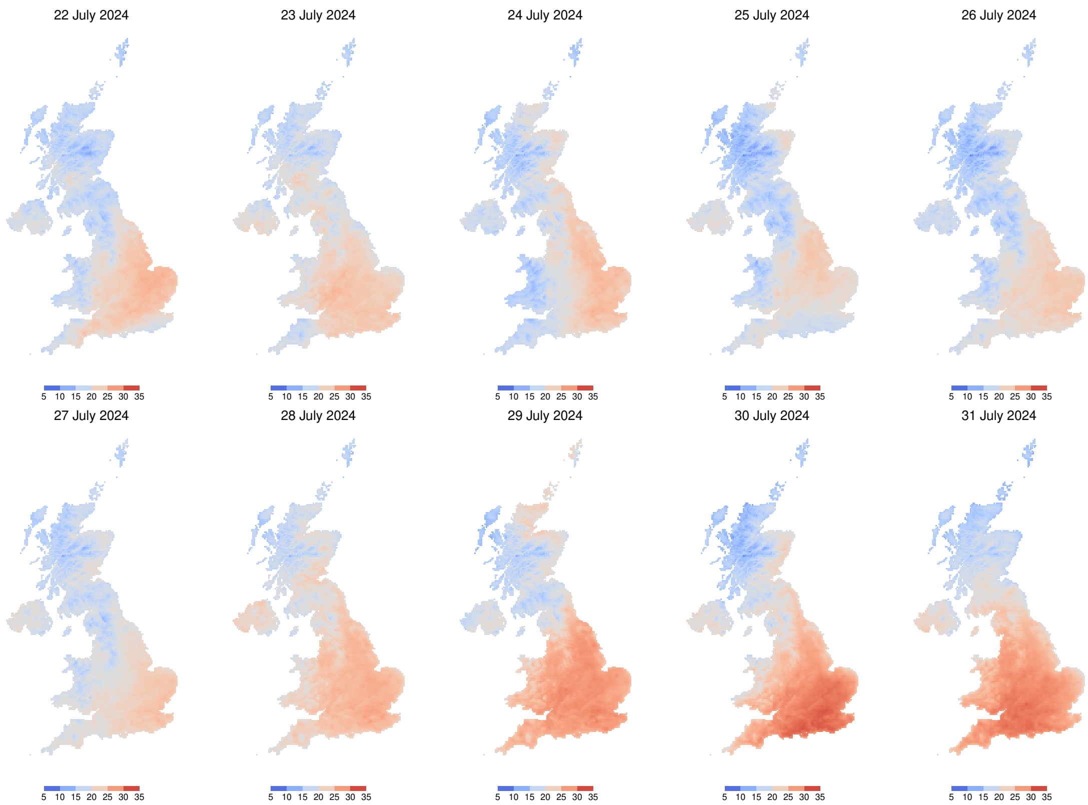

Figure 2: Maximum daily temperatures in July 2024

4. Methods

4.1. Empirical framework

We explore several outcome variables to investigate the effects of heat and adaptation on the UK labour force. In the first specification, our outcome is a binary variable which takes a value of 1 if an individual reported having worked fewer hours than average during the heat episode, else zero. In an alternative specification, we use the log of weekly hours worked. Our survey specifically asked respondents to compare their work hours during the heat episode to their typical work patterns for the same period, thus controlling for regular seasonal fluctuations. In a second specification, we investigate whether workers reduced their effort during the heat episode, which we use as a proxy for labour productivity. To explore the impact on worker health, we look into whether a worker reported suffering from heat-related adverse health conditions during the heat episode. We then explore the determinants of adaptation strategies adopted by the respondents. Our primary data collected in 2024 are geo-referenced, allowing us to merge these data with high-resolution temperature anomaly data from the UK Met Office.

Our study design uses variation in temperature anomalies across geographic locations and time during the July 2024 heat episode in the UK, rather than a traditional control-treatment design. While most survey respondents experienced the heat episode to some degree, the intensity of exposure varied substantially across the country, creating natural variation in our sample. Rather than a binary treatment-control design, our approach leverages continuous variation in temperature anomalies (deviation from 1961-1990 long-term July averages) as a measure of treatment intensity. This spatial variation in temperature anomalies serves as our primary explanatory variable of interest, essentially creating a spectrum of exposure intensities rather than discrete treatment and control groups.

We control for a rich set of covariates (Equation 1) including daily temperature anomaly from the long-term average for July during 1961-1990 (T_r) using the HadUK-Grid 1KM $\times$ 1KM data from the UK Met Office, individual characteristics of workers such as age and existing health conditions, and type of contracts ($\phi \boldsymbol{D}_i$), heat exposure levels of sectors that the worker is employed in and physical demands of the job ($\phi \boldsymbol{D}_i$). These variables in effect capture differences in seasonal work patterns across different employment arrangements. We also include adaptation undertaken including changing shifts and location of work during high heat days and whether the worker received a heat alert, and whether a worker was able to adapt ($\rho \boldsymbol{A}_i$), and adaptation undertaken by employers ($\pi \boldsymbol{E}_i$). We also control for region (ITL3 which mirrors previous NUTS3 classification) fixed-effects (α_r). We use a Logit regression framework (Shayegh and Dasgupta, 2022; Schleypen et al., 2022; Dasgupta et al., 2021; Antonelli et al., 2020; Shayegh et al., 2020).

$$y_i = \alpha_r + T_i + \phi \boldsymbol{D}_i + \delta \boldsymbol{X}_i + \rho \boldsymbol{A}_i + \pi \boldsymbol{E}_i + \epsilon_i \tag{1}$$

4.2. Data

We conducted an online survey of 2,007 workers in the UK between 2 and 8 August 2024 using Qualtrics. The survey consisted of a representative sample of the UK labour force to explore their experiences of the period of heat in the last two weeks of July. In our survey, 75.3% of the respondents were employed, 9.4% self-employed, 3.1% unemployed or looking for a job, and 1.3% were working in the gig economy. 47% of the respondents were female, compared to 47.6% of the UK labour force. Our sample reflects well the regional breakdown of the UK labour force, with 85.7% of the respondents being from England (84.6% reported in the UK LFS), 1.7% from Northern Ireland (2.7% reported in the UK LFS), 8.1% from Scotland (8.3% reported in the UK LFS), and 4.5% from Wales (4.4% reported in the UK LFS). 1.3% of the those that are employed responded to be working in the high-exposure sectors of agriculture, forestry and fishing, mining and quarrying (1.1% reported in the UK LFS), 7.2% in manufacturing (7.2% reported in the UK LFS), and 86.1% in the services sector (84.5% reported in the UK LFS).

We calculate the post-stratification weight for each respondent as the ratio of the population proportion to the sample proportion for each characteristic category, using information from the 2023 round of the UK Labour Force Survey (LFS) based on age, gender, ethnicity, region of work, and industry of main job.

5. Results

We first consider some of the key descriptive statistics that enable us to build up the first quantitative and UK representative picture of how workers in the UK, who were surveyed just after a period of heat in summer 2024, feel that heat is affecting their health and their working patterns. We then present the results of our empirical analysis that focuses specifically on the extent to which workers were able to adapt their working patterns during the heat and the overall impact on the hours they worked and perceived impacts on health.

5.1. *Descriptive statistics*

During the UK's heat episode in summer 2024, 76.8% of the labour force was working in areas where the temperature anomaly was at least 0.5°C above long-term average for the month of July during 1961-1990, and 8.4% of the workers were working in locations where temperature anomaly was greater than 1°C above long-term average. These temperature anomalies occurred across England and the three devolved nations. Even though temperatures were not high enough to be classified as a heatwave, many workers reported experiencing negative health impacts from the heat, which affected their health and the number of hours they were able to work (labour supply) and the level of effort during these working hours (labour productivity).

Our representative survey of how workers in the UK experienced a period of heat during Summer 2024 reveals a number of key insights. First, 49.4% of our sample reported working without access to air conditioning or other cooling in their workplace. Second, just under a third of those sampled felt that the heat episode had harmed their health, with those working night shifts more likely to report negative health impacts: 29% of those working day shifts, 39.7% of those working during the evening, and 36.2% working night shifts. Third, the health effects identified by respondents were predominantly symptoms of heat stroke or heat exhaustion, such as headaches or dizziness. Only around 4% of respondents reported suffering an accident or injury at work, and it is not possible to determine whether this was a greater percentage than outside of the heat episode. Fourth, workers undertook a wide variety of measures to adapt to the heat, including starting work earlier or later (around 16%), finishing work earlier or later (around 13%), and working fewer or more hours (around 7%). Around 13% of workers took more rest breaks whilst some took fewer; and almost a third of workers reported drinking water or other fluids more often. Just around 13% said that they didn't change their work behaviours due to heat. Some people were able to change where they worked or how they got to work, predominantly those working in London.

Almost a fifth of those employed said that their employer had implemented changes to the workplace to tackle heat, such as installing air conditioning, increasing ventilation, or increasing access to shade. Other adaptations explicitly offered by employers included providing greater access to fluids, increasing the frequency of rest breaks, reducing time spent working outside, and allowing workers to reduce their effort at work. Just over one third of employees said that their employer had not made any adjustments to help them adapt to the heat.

47.6% of the total respondents and 63.2% of the employed respondents reported receiving some kind advanced warning or alert regarding a heatwave or high heat in the previous two weeks. Among those who received an alert, 24.5% reported receiving alerts from their employers, 40.0% from the Met Office or another public institution, and 33.7% from the media such as the BBC.

5.2. *Empirical results*

From the descriptive statistics above it is clear that UK workers were affected by the summer 2024 heat episode; and that both workers and employers undertook a wide range of efforts to reduce the negative impacts of heat. Yet despite this, many of the people we surveyed felt that still their health had been harmed. Here we explore which workers were most able to adapt to the heat to protect their health, and what adaptations were linked to workers changing their labour supply and effort at work.

First, we determine whether or not an individual worked fewer hours during the heat episode than their normal working hours, controlling for other determinants (Table 1; columns 1-2). Our findings suggest a clear link between the temperature anomaly and workers reducing their hours worked. A 1°C positive temperature anomaly from the long-term average increases the probability of a worker reducing their hours by 9.9% and effort by 9.5%. However, for workers who received a heat alert, the effect is 3.7%. Contract type matters. We find that those paid by the hour, paid on commission, and paid piece-rate, are more likely to reduce their hours worked as a consequence of the heat episode than those paid a salary. This suggests that job security may play a significant role in workers being able to be flexible during high heat days.

We find clear evidence that adaptation, specifically the ability to change shifts and change work location during high heat days, makes it less likely that workers will reduce their hours due to heat. Workers in high exposure sectors, those with pre-existing health conditions, and those that undertake physically demanding work, are more likely to reduce their hours worked, suggesting that they are making greater efforts to protect their health. Workers who were able to change their work shifts or work from a different location reduced their probability working fewer hours by 6.3% and 4.3% respectively.

We include a number of interaction terms to explore the effects of adaptation strategies that include heat alerts. We find that workers who received an alert in the form of early warning of the impending heat episode were less likely to reduce their hours worked, suggesting that early warning systems might allow workers to plan ahead of time. Alerts were particularly effective in reducing negative effects on working hours for workers in high-exposure sectors and those workers in physically demanding occupations.

Finally, if employers had implemented changes to the work environment by installing air conditioning or increasing ventilation or access to shaded areas, or if they had provided greater access to fluids for workers to stay hydrated, increased the frequency of rest breaks, or reduced the duration of outdoor work, workers had a lower reduction in working hours.

Adaptation strategies reduce the heat-related burden on the UK labour force to some extent. Our results suggest that a 1°C increase in temperature anomaly potentially reduces the number of hours worked among the UK labour force by 106.6 million hours. However, a wider rollout of heat alerts could potentially result in avoided loss of 66.7 million hours. Empowering workers by allowing them flexible working hours and locations could reduce heat stress induced loss in labour supply by between 47 million and 60 million working hours. On the other hand, employers' adaptation actions could reduce working hour losses by between 41 million and 50 million working hours.

Our findings (Table 1; columns 3-4) show impacts on labour productivity (defined in terms of reduced effort at work during the previous two weeks) to be consistent with impact on hours worked. The coefficients are consistent in terms of both magnitude and statistical significance. And similarly, early heat warnings and adaptation by workers and employers reduce the negative effect on labour productivity.

Table 1: Effect on labour supply and labour productivity (probability)

	(1)	(2)	(3)	(4)
	Reduced hours (Logit)	Reduced hours (Logit)	Reduced effort (Logit)	Reduced effort (Logit)
Alert	-0.041**	-0.045**	-0.036**	-0.039**
	(0.027)	(0.016)	(0.015)	(0.018)
Max temperature anomaly	0.091***	0.099***	0.085***	0.095***
	(0.000)	(0.001)	(0.000)	(0.001)
Alert#Max temperature anomaly	-0.054***	-0.062***	-0.044***	-0.049***
	(0.002)	(0.006)	(0.009)	(0.002)
Age (reference category: 25-34)				
18-24	0.032**	0.033**	0.026***	0.028***
	(0.024)	(0.019)	(0.004)	(0.008)
35-40	0.036	0.031	0.034	0.030
	(0.217)	(0.200)	(0.336)	(0.307)
40-49	0.028	0.024	0.039	0.022
	(0.304)	(0.441)	(0.228)	(0.339)
50-59	0.046**	0.045**	0.045**	0.037**
	(0.020)	(0.024)	(0.015)	(0.012)
60 and above	0.057***	0.055***	0.056***	0.050***
	(0.000)	(0.000)	(0.004)	(0.007)
Female (reference category: male)	0.063***	0.060***	0.064**	0.059**
	(0.000)	(0.000)	(0.022)	(0.029)
On holiday	0.317***	0.301***	0.115	0.110
	(0.000)	(0.000)	(0.185)	(0.200)
Exposure (reference category: low-exposure sectors)				
High-exposure	0.163**	0.160**	0.156***	0.153***
	(0.029)	(0.023)	(0.003)	(0.009)
Services	-0.077	-0.070	-0.067	-0.060
	(0.331)	(0.258)	(0.553)	(0.504)
High-exposure#Alert	-0.059**	-0.057**	-0.056***	-0.051***
	(0.015)	(0.021)	(0.004)	(0.000)
Services#Alert	-0.011	-0.008	-0.015	-0.012
	(0.357)	(0.229)	(0.637)	(0.600)
Able to change shifts	-0.049**	-0.044***	-0.045***	-0.042***
	(0.030)	(0.009)	(0.001)	(0.000)
Changed work location	-0.058***	-0.056***	-0.053***	-0.050***
	(0.008)	(0.000)	(0.001)	(0.004)
Existing health conditions	0.178***	0.174***	0.162***	0.158***
	(0.007)	(0.000)	(0.000)	(0.002)
Physically demanding work	0.188**	0.184**	0.196***	0.187***
	(0.035)	(0.027)	(0.003)	(0.006)
Physically demanding work#Max temperature anomaly		0.068***		0.061***
		(0.000)		(0.001)
Contract type (payment)				
Paid by the hour		0.051**		0.043**
		(0.014)		(0.022)
Commission-based pay		0.049**		0.040**
		(0.031)		(0.027)
Piece-rate pay		0.031**		0.028**
		(0.029)		(0.019)
Employer changed work environment		-0.046***		-0.049***
		(0.002)		(0.009)
Employer changed hydration		-0.039***		-0.031***
		(0.005)		(0.007)
Employer changed outdoor work policy		-0.034		-0.028**
		(0.444)		(0.019)
Number of observations	1,726	1,435	1,721	1,430
Region FE	YES	YES	YES	YES
Working arrangements FE	YES	YES	YES	YES

Robust p-values in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Table 2 focuses on the health impacts of heat. We find strong evidence that adaptation and higher adaptative capacity reduce the negative impact of heat on workers' perceptions of their health, and that some workers are more able than others to adapt and to benefit from adaptation. First, our analysis suggests that heat stress does appear to be harming worker health, adaptation notwithstanding. But by including a temperature anomaly-alert interaction, we have evidence to suggest that advanced warning of high heat events allows workers to plan ahead to protect their health and reduces the negative effects on health by approximately 5 percentage-points, underlying the importance of early warning systems. As we might expect, older and younger workers are more likely to perceive their health to be harmed by heat, similarly those working in high-exposure sectors, those with existing health conditions, and those undertaking physically demanding work. Just as adaptations allow workers to reduce the negative impact of heat on working hours, so too do they enable workers to protect their health. Being able to change shifts or working locations reduced the probability of workers reporting negative health effects due to heat stress by 3.5%. Workers whose employers have introduced adaptations also appear to be less likely to perceive their health harmed during the heat episode. This finding suggests that employers that invest in adapting work environments to heat not only avoid reduction in labour supply and labour productivity due to heat stress but their workers also report fewer heat-related health problems, which reduces absenteeism.

Table 2: Regression with health impacts (probability)

	(1)	(2)
	Health harmed (Logit)	Health harmed (Logit)
Alert	-0.059**	-0.060**
	(0.011)	(0.019)
Max temperature anomaly	0.094***	0.091***
	(0.005)	(0.000)
Alert#Max temperature anomaly	-0.043***	-0.051***
	(0.000)	(0.002)
Age (reference category: 25-34)		
18-24	0.019**	0.021**
	(0.027)	(0.020)
35-40	0.012	0.009
	(0.277)	(0.205)
40-49	0.020	0.014
	(0.339)	(0.212)
50-59	0.026**	0.021**
	(0.018)	(0.022)
60 and above	0.031***	0.037***
	(0.000)	(0.000)
Female (reference category: male)	0.066***	0.071***
	(0.000)	(0.001)
On holiday	0.104	0.117
	(0.166)	(0.231)
Exposure (reference category: low-exposure sectors)		
High-exposure	0.124**	0.129**
	(0.041)	(0.035)
Services	-0.144	-0.155
	(0.341)	(0.302)
High-exposure#Alert	-0.051**	-0.055**
	(0.028)	(0.024)
Services#Alert	-0.041	-0.078
	(0.222)	(0.159)
Able to change shifts	-0.047***	-0.052***
	(0.003)	(0.000)
Changed work location	-0.052***	-0.055***
	(0.000)	(0.002)
Existing health conditions	0.181***	0.189***
	(0.000)	(0.004)
Physically demanding work	0.200**	0.191**
	(0.033)	(0.028)
Physically demanding work#Max temperature anomaly	0.165***	0.174***
	(0.009)	(0.000)
Contract type (payment)		
Paid by the hour		0.040***
		(0.000)
Commission-based pay		0.034**
		(0.021)
Piece-rate pay		0.021**
		(0.029)
Employer changed work environment		-0.033***
		(0.000)
Employer changed hydration		-0.038***
		(0.001)
Employer changed outdoor work policy		-0.024**
		(0.021)
Number of observations	1,726	1,435
Region FE	YES	YES
Working arrangements FE	YES	YES

Robust p-values in parentheses
*** p<0.01, ** p<0.05, * p<0.1

5.3. *Heckman correction*

In order to test for potential selection bias, we use a Heckman correction to control for the possibility that workers who chose not to work during the high heat days might systematically differ from those who choose to work. The Heckman approach provides several advantages for heat impact research. Conceptually, it aligns with theoretical models of temperature effects on labour supply that recognize both extensive margin (participation) and intensive margin (hours) adjustments. This is particularly relevant for heat studies as research shows workers in climate-exposed sectors report fewer hours spent at work on high heat days (Dasgupta et al., 2024, 2021). For our exclusion restriction in the Heckman selection model framework we use data on whether someone typically uses public transport as their main mode of getting to work. This is an appealing candidate because it meets two primary requirements for an effective exclusion restriction and valid identification strategy. It influences selection (working during heat) through, for example, service disruptions, commuters facing increased discomfort on crowded, potentially inadequately cooled vehicles during heat episodes, and waiting at bus stops or train platforms during extreme heat which increases heat exposure before work. However, it does not directly affect outcome variables for those who do work during the heat episode.

Undertaking the Heckman correction, our results suggest that workers who use public transport to get to work are 11.7% less likely to work during high heat days than those who do not use public transport, ceteris paribus. These results notwithstanding, the Heckman-corrected results are largely consistent with the previous results, that heat stress significantly affects UK labour supply and labour productivity, with adaptation measures providing partial mitigation.

We undertake a second Heckman correction (Table S2 in Appendix A), using access to air conditioning at home as the exclusion restriction. In this case, our results suggest that workers with home air conditioning reduce their hours on average by 9.6% compared to those without. We recognise that in the UK, only a small minority of households have home air conditioning.

Table 3: Effect on labour supply and labour productivity (Heckman correction)

	(1) Reduced hours	(2) Reduced effort
Alert	-0.049**	-0.044**
	(0.022)	(0.012)
Max temperature anomaly	0.095***	0.099***
	(0.000)	(0.000)
Alert#Max temperature anomaly	-0.068***	-0.053***
	(0.002)	(0.008)
Age (reference category: 25-34)		
18-24	0.032**	0.026***
	(0.011)	(0.003)
35-40	0.030	0.023
	(0.335)	(0.225)
40-49	0.021	0.025
	(0.304)	(0.301)
50-59	0.041**	0.034**
	(0.020)	(0.019)
60 and above	0.058***	0.055***
	(0.000)	(0.008)
Female (reference category: male)	0.067***	0.062**
	(0.005)	(0.037)
On holiday	0.342***	0.127*
	(0.000)	(0.057)
Exposure (reference category: low-exposure sectors)		
High-exposure	0.165**	0.160***
	(0.029)	(0.002)

	(1) Reduced hours	(2) Reduced effort
Services	-0.077	-0.064
	(0.552)	(0.257)
High-exposure#Alert	-0.063***	-0.056***
	(0.007)	(0.001)
Services#Alert	-0.004	-0.016
	(0.369)	(0.244)
Able to change shifts	-0.058***	-0.046***
	(0.001)	(0.000)
Changed work location	-0.063***	-0.054***
	(0.001)	(0.001)
Existing health conditions	0.181***	0.167***
	(0.002)	(0.007)
Physically demanding work	0.198**	0.181***
	(0.015)	(0.000)
Physically demanding work#Max temperature anomaly	0.073***	0.054***
	(0.009)	(0.009)
Contract type (payment)		
Paid by the hour	0.058**	0.041**
	(0.025)	(0.026)
Commission-based pay	0.057**	0.043**
	(0.024)	(0.021)
Piece-rate pay	0.047**	0.034**
	(0.020)	(0.002)
Employer changed work environment	-0.042***	-0.048**
	(0.000)	(0.017)
Employer changed hydration	-0.044***	-0.031**
	(0.000)	(0.021)
Employer changed outdoor work policy	-0.030	-0.036**
	(0.321)	(0.011)
Public transport commute	-0.117***	-0.125**
	(0.000)	(0.040)
Alert	-0.025**	-0.021**
	(0.016)	(0.015)
Max temperature anomaly	0.112***	0.085***
	(0.000)	(0.006)
Alert#Max temperature anomaly	-0.030**	-0.028***
	(0.031)	(0.000)
Age (reference category: 25-34)		
18-24	0.018**	0.020***
	(0.019)	(0.001)
35-40	0.021	0.020
	(0.227)	(0.552)
40-49	0.023	0.017
	(0.459)	(0.411)
50-59	0.027**	0.024**
	(0.028)	(0.016)
60 and above	0.039***	0.042***
	(0.009)	(0.000)
Female (reference category: male)	0.053***	0.046**
	(0.005)	(0.046)
On holiday	0.300***	0.247**
	(0.000)	(0.024)
Exposure (reference category: low-exposure sectors)		
High-exposure	0.124**	0.110**
	(0.041)	(0.014)
Services	-0.050	-0.041
	(0.501)	(0.223)
High-exposure#Alert	-0.052***	-0.048***
	(0.000)	(0.006)
Services#Alert	-0.010	-0.011
	(0.201)	(0.204)
Able to change shifts	-0.062***	-0.052***
	(0.000)	(0.000)
Changed work location	-0.040***	-0.036***
	(0.008)	(0.000)
Existing health conditions	0.192***	0.182***
	(0.004)	(0.002)
Physically demanding work	0.300**	0.258***
	(0.024)	(0.008)
Physically demanding work#Max temperature anomaly	0.065***	0.051***
	(0.000)	(0.003)
Contract type (payment)		

	(1) Reduced hours	(2) Reduced effort
Paid by the hour	0.060**	0.052**
	(0.020)	(0.033)
Commission-based pay	0.050**	0.031**
	(0.032)	(0.029)
Piece-rate pay	0.040**	0.038**
	(0.043)	(0.007)
Employer changed work environment	-0.031**	-0.036**
	(0.036)	(0.027)
Employer changed hydration	-0.039***	-0.029**
	(0.001)	(0.029)
Employer changed outdoor work policy	-0.024	-0.030**
	(0.157)	(0.029)
Region FE	YES	YES
Working arrangements FE	YES	YES
/athrho	0.563	0.654
ρ	0.510	0.698

Robust p-values in parentheses. *** p<0.01, ** p<0.05, * p<0.1

5.4. Determinants of adaptation

In this section, we explore the determinants of adaptation and behavioural changes among the UK workforce during periods of high heat using a multinomial Logit framework, which simultaneously estimating all strategy probabilities rather than chaining binary decisions. In this case, the base outcome is "No adaptation or behaviour changes," with six alternative strategies modelled as separate categorical outcomes. The findings show that that heat alerts, temperature anomalies, occupational exposure levels, and employer support structures significantly influence adaptation behaviours.

Workers in high-exposure sectors exhibit 8.1–9.1% higher likelihoods of adopting at least one adaptive measure compared to low-exposure counterparts, while each 1°C temperature when during the day they work by 6.6–7.0%. Critically, workers who received alerts in advance of the heat period had a 2.1–3.8% higher probability of adopting at least one adaptation strategy than those who did not receive an alert. Workers in high-exposure sectors show 5.7–9.1% higher adaptation probabilities compared to low-exposure sectors. Physically demanding work increases adaptation probabilities by 6.4–13.8%, with higher adaptation probabilities at higher temperature anomalies. In terms of contract types, workers on hourly wages and piece-rate commissions are less likely yo undertake adaptation, suggesting power imbalance creates perverse incentives against heat safety. A lack of employer support reduce adaptation odds by 4.3–8.8%, highlighting systemic barriers to heat resilience and could be a sign of inflexibility.

Table 4: Determinants of adaptation and behavioural changes

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
	Logit	Multinomial Logit					
	Any adaptation	Change shifts	Rest breaks	Change hours	Hydration	Change location	Change transport
Alert	0.039**	0.030**	0.040**	0.033***	0.021**	0.016**	0.012**
	(0.023)	(0.018)	(0.029)	(0.005)	(0.029)	(0.022)	(0.015)
Max temperature anomaly	0.059**	0.066***	0.048**	0.070***	0.052***	0.043***	0.037***
	(0.032)	(0.001)	(0.017)	(0.009)	(0.004)	(0.002)	(0.001)
Alert#Max temperature anomaly	0.037***	0.033***	0.027***	0.038***	0.026***	0.027**	0.021***
	(0.004)	(0.009)	(0.008)	(0.004)	(0.002)	(0.019)	(0.008)
Age (reference category: 25-34)							
18-24	-0.027**	-0.021*	-0.015**	-0.024***	-0.018***	-0.015***	-0.018*
	(0.046)	(0.055)	(0.026)	(0.003)	(0.005)	(0.006)	(0.057)
35-40	0.030	0.027	0.023	0.039	0.018	0.023	0.022
	(0.111)	(0.304)	(0.367)	(0.440)	(0.333)	(0.405)	(0.307)
40-49	0.023	0.018	0.021	0.024	0.024	0.014	0.020
	(0.203)	(0.155)	(0.169)	(0.556)	(0.153)	(0.236)	(0.677)
50-59	0.033**	0.027**	0.019**	0.031**	0.024**	0.025**	0.028***
	(0.029)	(0.023)	(0.029)	(0.027)	(0.019)	(0.032)	(0.000)
60 and above	0.043**	0.048**	0.039***	0.063***	0.044***	0.037***	0.059**
	(0.021)	(0.024)	(0.001)	(0.001)	(0.000)	(0.009)	(0.039)
Female (reference category: male)	-0.053***	-0.047***	-0.042***	-0.051**	0.037**	-0.040**	0.042**
	(0.009)	(0.002)	(0.005)	(0.033)	(0.022)	(0.045)	(0.026)
On holiday	-0.034	-0.027	-0.027	-0.098	-0.028	-0.102	-0.066
	(0.222)	(0.207)	(0.445)	(0.199)	(0.303)	(0.288)	(0.558)
Exposure (reference category: low-exposure sectors)							
High-exposure	0.081**	0.089**	0.072**	0.091***	0.064***	0.057**	0.091***
	(0.011)	(0.015)	(0.016)	(0.006)	(0.001)	(0.033)	(0.000)
Services	-0.040	-0.059	-0.053	-0.050	-0.041	-0.058	-0.081**
	(0.208)	(0.307)	(0.151)	(0.224)	(0.353)	(0.331)	(0.018)
High-exposure#Alert	0.075**	0.081**	-0.057**	-0.063***	-0.045***	-0.052**	-0.027**
	(0.027)	(0.013)	(0.017)	(0.000)	(0.000)	(0.016)	(0.030)
Services#Alert	-0.012	-0.027	-0.021	-0.051	-0.018	-0.058	-0.033
	(0.159)	(0.300)	(0.220)	(0.208)	(0.404)	(0.233)	(0.455)
Existing health conditions	0.134**	0.149**	0.120***	0.157***	0.085***	0.106**	0.070***
	(0.030)	(0.017)	(0.000)	(0.000)	(0.006)	(0.030)	(0.000)
Physically demanding work	0.118**	0.123**	0.101**	0.138***	0.086***	0.101***	0.064**
	(0.013)	(0.024)	(0.012)	(0.007)	(0.000)	(0.006)	(0.029)
Physically demanding work#Max temperature anomaly	0.045***	0.057***	0.042***	0.046***	0.039***	0.034**	0.049**
	(0.006)	(0.002)	(0.001)	(0.003)	(0.007)	(0.019)	(0.036)
Contract type (payment)							
Paid by the hour	-0.055**	-0.063**	-0.055**	-0.024	-0.029**	-0.029	-0.023***
	(0.020)	(0.019)	(0.013)	(0.133)	(0.025)	(0.145)	(0.000)
Commission-based pay	-0.035**	-0.040**	-0.037**	-0.053*	-0.031**	-0.039**	-0.027**
	(0.023)	(0.026)	(0.026)	(0.056)	(0.015)	(0.023)	(0.011)
Piece-rate pay	-0.032**	-0.039**	-0.030**	-0.023**	-0.020**	-0.031**	-0.031**
	(0.012)	(0.018)	(0.022)	(0.012)	(0.011)	(0.019)	(0.015)
Lack of control of work environment	-0.077***	-0.094***	-0.071**	-0.085***	-0.065**	-0.061***	-0.081**
	(0.000)	(0.006)	(0.032)	(0.000)	(0.016)	(0.008)	(0.031)
Lack of support from employer	-0.067***	-0.088***	-0.060***	-0.069***	-0.053***	-0.050***	-0.043**
	(0.001)	(0.000)	(0.009)	(0.001)	(0.000)	(0.006)	(0.041)
Number of observations	1,671	1,671	1,671	1,671	1,671	1,671	1,671
Region FE	YES	YES	YES	YES	YES	YES	YES
Working arrangements FE	YES	YES	YES	YES	YES	YES	YES

Robust p-values in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Base outcome: No adaptation or behaviour changes

6. Discussion and implications for policy

In this paper, we collected a unique primary dataset that provides the first detailed and quantitative assessment of how workers are affected by heat in the UK. By addressing the impact on labour supply, labour productivity, and worker health, we make an important contribution to the nascent but growing literature on climate change, health, and the economy. Without this type of detailed and granular understanding of the economic and health implications of heat on the labour force, it is challenging for policy makers to design efficient and equitable policies that support sustainable growth during this era of climate change, through protecting workers' health and productivity. Our empirical framework analyses the plausible causal impact of heat stress on labour outcomes while controlling for a rich set of individual and workplace characteristics. As such, it provides a robust framework for investigating the effects of heat stress on the UK labour force and the effectiveness of various adaptation strategies.

Our research reveals important insights. Workers perceive their health to be harmed by heat, and they take, albeit limited, actions to protect their health. Similarly, employers have introduced a wide range of adaptation measures, and these adaptation measures are at least partially effective. But adaptation is clearly incomplete, even when the temperature anomaly is not so high as to imply a heatwave, and temperatures are considerably lower than experienced in the UK in 2022. Government and public sector efforts to warn workers of impending heat appear to work, suggesting that workers do take note and do act on these warnings, where they can. Our findings show that adaptation reduce the heat-related burden on the UK labour force to some extent, with early-warning systems having the potential to reduce losses in labour supply by two-thirds.

Just as adaptations allow workers to reduce the negative impact of heat on working hours and productivity, so too do they enable workers to protect their health. Our findings suggest that Workers whose employers have introduced adaptations appear to be less likely to perceive their health as having been harmed during the heat episode, emphasising that employers that invest in adapting work environments to heat are likely to not only avoid reduction in labour supply and labour productivity due to heat stress but their workers also report fewer heat-related health problems, which reduces absenteeism.

There are a number of broader implications and observations that come out of the existing literature and our research. In the UK, adaptation efforts are likely to primarily focus on transforming the workforce and workplace, including their systems and processes (Trade Union Congress, 2009). Mandatory adaptation reporting could incentivise businesses to prioritize addressing climate risks, though arguably this is hindered by the UK government's current voluntary reporting framework (Surminski et al., 2021). Given that heat and heatwaves are only going to become more frequent and more intense, it is likely going to be important to establish a "culture of heat" in the UK, to ensure more employers and workers are pre-prepared to reduce the negative implications of heat on the workforce. Learning from cities or countries that already have a culture of heat, such as Paris which has a district cooling system, can enhance public awareness of climate risks, increase protection of vulnerable populations, and encourage workers and employers to take necessary actions in anticipation of heat and heatwaves (Howarth et al., 2023).

In some work environments, it may be more tricky to adapt. For example, while workers in most types of work can change what they wear to adapt to high temperatures, the design of uniforms and specific PPE equipment for firefighters and paramedics has not yet been comfortable enough during extreme heat (Howarth et al., 2023). These workers must follow a prescriptive dress code when working to protect themselves from the potential risks brought by fire and infections, which can put them at greater risk of heat stress (Dasgupta et al., 2024; Dasgupta and Robinson, 2023; Howarth et al., 2023). Therefore, other adaptation strategies need to be considered.

Finally, because there is so little detailed information on how worker health and productivity is affected by heat, we do not know the extent to which an improved understanding, with sufficiently granular data, could enable both worker health and employer profits to be enhanced through better adaptation to heat in the workplace, and where explicit government actions are needed to protect workers where there is a health-profit trade-off and to minimise any such trade-offs.

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Appendix A. Appendix A

Table S1: Regression with labour supply

	(1)	(2)
	Labour supply (Poisson)	Labour supply (Poisson)
Alert	0.013**	0.014**
	(0.038)	(0.025)
Max temperature anomaly	-0.021***	-0.024***
	(0.002)	(0.003)
Alert#Max temperature anomaly	0.006***	
	(0.000)	
Age (reference category: 25-34)		
18-24	-0.130***	-0.128***
	(0.000)	(0.001)
35-40	0.080***	0.080***
	(0.000)	(0.000)
40-49	0.026***	0.028***
	(0.013)	(0.016)
50-59	-0.005	-0.005
	(0.686)	(0.771
60 and above	-0.131***	-0.133***
	(0.000)	(0.000)
Female (reference category: male)	-0.198***	-0.192***
	(0.000)	(0.001)
Exposure (reference category: low-exposure sectors)		
High-exposure	-0.101***	-0.103***
	(0.000)	(0.004)
Services	0.112***	0.114***
	(0.000)	(0.000)
High-exposure#Alert		0.016***
		(0.001)
Services#Alert		0.008
		(0.227)
Able to change shifts	0.105**	0.111**
	(0.025)	(0.019)
Changed work location	0.005***	0.004***
	(0.000)	(0.002)
Existing health conditions	-0.025***	-0.028***
	(0.000)	(0.002)
Physically demanding work	-0.034***	-0.038***
	(0.000)	(0.007)
Contract type (payment)		
Paid by the hour	-0.017***	-0.021***
	(0.006)	(0.002)
Commission-based pay	-0.007***	-0.004***
	(0.002)	(0.000)
Piece-rate pay	-0.011**	-0.015**
	(0.019)	(0.031)
Employer changed work environment	0.045***	0.038***
	(0.000)	(0.000)
Employer changed hydration	0.001***	0.002***
	(0.000)	(0.002)
Employer changed outdoor work policy	0.002	0.007
	(0.258)	(0.331)
Number of observations	1,438	1,435
Region FE	YES	YES
Working arrangements FE	YES	YES

Robust p-values in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Table S2: Effect on labour supply and labour productivity (Heckman correction using access to air conditioning at home)

	(1)	(2)
	Reduced hours	Reduced effort
Alert	-0.045**	-0.040**
	(0.028)	(0.017)
Max temperature anomaly	0.093***	0.094***
	(0.001)	(0.002)
Alert#Max temperature anomaly	-0.064***	-0.050***
	(0.000)	(0.002)
Age (reference category: 25-34)		
18-24	0.030**	0.022***
	(0.019)	(0.006)
35-40	0.035	0.025
	(0.308)	(0.211)
40-49	0.024	0.022
	(0.411)	(0.377)
50-59	0.037**	0.036**
	(0.023)	(0.012)
60 and above	0.062***	0.050***
	(0.002)	(0.000)
Female (reference category: male)	0.064***	0.060**
	(0.000)	(0.031)
On holiday	0.348***	0.120*
	(0.000)	(0.052)
Exposure (reference category: low-exposure sectors)		
High-exposure	0.161**	0.152***
	(0.016)	(0.009)
Services	-0.070	-0.069
	(0.500)	(0.331)
High-exposure#Alert	-0.060***	-0.051***
	(0.000)	(0.009)
Services#Alert	-0.006	-0.019
	(0.308)	(0.240)
Able to change shifts	-0.054***	-0.040***
	(0.009)	(0.000)
Changed work location	-0.069***	-0.050***
	(0.000)	(0.003)
Existing health conditions	0.186***	0.160***
	(0.000)	(0.002)
Physically demanding work	0.194**	0.172***
	(0.019)	(0.000)
Physically demanding work#Max temperature anomaly	0.075***	0.058***
	(0.007)	(0.001)
Contract type (payment)		
Paid by the hour	0.054**	0.045**
	(0.021)	(0.020)
Commission-based pay	0.053**	0.040**
	(0.029)	(0.027)
Piece-rate pay	0.044**	0.038**
	(0.011)	(0.000)
Employer changed work environment	-0.034***	-0.040**
	(0.001)	(0.022)
Employer changed hydration	-0.030***	-0.037**
	(0.002)	(0.020)
Employer changed outdoor work policy	-0.035	-0.030**
	(0.444)	(0.018)
Air conditioning at home	-0.096***	-0.0066**
	(0.006)	(0.032)
Alert	-0.023**	-0.017**
	(0.012)	(0.011)
Max temperature anomaly	0.114***	0.074***
	(0.000)	(0.009)
Alert#Max temperature anomaly	-0.033**	-0.021***
	(0.034)	(0.000)
Age (reference category: 25-34)		
18-24	0.016**	0.016**
	(0.013)	(0.028)
35-40	0.020	0.021
	(0.200)	(0.500)
40-49	0.028	0.010
	(0.432)	(0.321)

	(1)	(2)
	Reduced hours	Reduced effort
50-59	0.025**	0.020**
	(0.022)	(0.026)
60 and above	0.041***	0.034***
	(0.004)	(0.002)
Female (reference category: male)	0.050***	0.040**
	(0.002)	(0.037)
On holiday	0.306***	0.240**
	(0.001)	(0.020)
Exposure (reference category: low-exposure sectors)		
High-exposure	0.127**	0.119**
	(0.026)	(0.019)
Services	-0.052	-0.047
	(0.401)	(0.314)
High-exposure#Alert	-0.053***	-0.040**
	(0.001)	(0.031)
Services#Alert	-0.018	-0.008
	(0.220)	(0.298)
Able to change shifts	-0.065***	-0.044***
	(0.001)	(0.001)
Changed work location	-0.044***	-0.031***
	(0.001)	(0.000)
Existing health conditions	0.195***	0.176***
	(0.001)	(0.000)
Physically demanding work	0.307**	0.241***
	(0.028)	(0.001)
Physically demanding work#Max temperature anomaly	0.060***	0.040***
	(0.001)	(0.009)
Contract type (payment)		
Paid by the hour	0.063**	0.050**
	(0.022)	(0.041)
Commission-based pay	0.058**	0.034**
	(0.035)	(0.020)
Piece-rate pay	0.042**	0.030**
	(0.036)	(0.000)
Employer changed work environment	-0.044**	-0.024**
	(0.030)	(0.020)
Employer changed hydration	-0.035***	-0.020**
	(0.003)	(0.021)
Employer changed outdoor work policy	-0.026	-0.026**
	(0.150)	(0.033)
Region FE	YES	YES
Working arrangements FE	YES	YES
/athrho	0.504	0.519
ρ	0.502	0.661